

# THE TASK FORCE ON AMERICAN INNOVATION



Oak Ridge National Lab's BAAM (Big Area Additive Manufacturing) machine developed in partnership with Cincinnati Incorporated.

## How Federal Investments in Science Created *A Revolution*

### The Story of 3D Printing & Additive Manufacturing

**Additive manufacturing (AM)**, commonly known as three-dimensional (3D) printing, is a set of layer-by-layer processes for producing 3D objects directly from a digital model. Since its inception a few decades ago, the AM industry has grown to almost \$3 billion as of 2012, and is poised to grow to more than \$6.5 billion through 2019.

Federal investment in basic science research was critical in the early development of AM. A report by the Institute for Defense Analysis' Science and Technology Policy Institute identified the Federal Government's role in supporting the development of AM across **three areas**:

- **Development through direct grant funding for early phases of private & university-level research and AM technology;**
- **Creation of knowledge, technologies, and tools by early, unrelated research that were later adopted in the AM field and applied by inventors to develop foundational AM patents and technologies;**
- **Knowledge diffusion from the foundational AM patents to improve later iterations of the technologies and develop new applications.**

#### The First SLS Machine



Carl Deckard and Joe Beaman of the University of Texas developed the first **Selective Laser Sintering (SLS)** Machine in 1987.

SLS, also known as powder-bed fusion, uses a heat source (like a laser) to fuse a powder material into a 3D object.



They were supported with seed funding through an NSF **Small Grant for Exploratory Research (SGER)**: "Part Generation by Layerwise Selective Sintering." These grants are known as "sugar" grants in the NSF community.

They also received a 1989 NSF SBIR grant, which directly led to the early commercialization of their technology.

The knowledge diffusion from Federally-sponsored research and development in the early 1970s influenced the patents filed in the 1980s–1990s and even later innovations. Powder-bed fusion (SLS) was particularly influenced from research supported by DOD sponsors, including the Navy and the Air Force. For example, the Office of Naval Research funded work by United Technologies Corporation in the late 1970s, almost a decade before Deckard's seminal SLS patent. In the 1980s, the Air Force supported research for material deposition using directed energy for semiconductor fabrication, which was later referenced by a patent that was cited by Deckard's patent family.

**The federal government was also instrumental in the early research that influenced modern AM, including funding several supportive AM technologies during the 1970s including development of computer numerical controlled machining and solid modeling tools.**

#### Lessons & Challenges for the Government

**To the extent feasible, providing consistent support with strategic intent would help sustain support for emerging areas of science and technology.**

Networking between industry and academia can be critical for the development of a field, and the government should explicitly support these types of interactions. Funding agencies could consider supporting both industry and academia more freely, perhaps through programs that facilitate more seamless university-industry collaboration.

The Federal Government funded AM research in academia, innovative small firms, standards development, and student training. Experts have underscored the importance of this ancillary support, particularly the training of students who go on to work and innovate in the private sector.





Lessons (continued)

In addition to the challenge of training the next generation of the skilled workforce and educating new engineers, the research needs for AM include:

- bringing down costs
- developing new materials
- achieving more consistency and standardization
- developing new computer aided design tools
- increasing process speeds
- advancing biological AM

Fortunately, federally funded basic science research at Oak Ridge National Laboratory (ORNL) and across the American University system is already addressing these challenges.



Leveraging Oak Ridge National Laboratory’s rich history in materials science, robotics, computing, sensors and controls, the **Manufacturing Demonstration Facility (MDF)** concurrently developed additive manufacturing systems, the materials used in the systems, and artificial intelligence-guided controls to precisely manufacture complex parts with significantly **less waste, time, energy, and cost.**

This holistic approach is uniquely suited to the national lab environment, where scientists and engineers from multiple disciplines combine their expertise and leverage unparalleled facilities ranging from supercomputers to atomic-level characterization tools in order to develop new materials, component designs, and to guide the manufacturing process.



The MDF at ORNL is the only DOE designated user facility focused on performing early-stage research and development to improve the energy and material efficiency, productivity, and competitiveness of American manufacturers. Their mission is to develop and aid the adoption of additive manufacturing and composite technologies within U.S. small-, medium-, and large-scale industries for clean energy applications.

The MDF is also DOE’s first research facility established to provide industry with affordable and convenient access to infrastructure, tools, and expertise to facilitate rapid adoption of advanced additive manufacturing technologies. They are supported and managed by DOE’s **Advanced Manufacturing Office**, which is also a member of the America Makes Government Advisory Board. **America Makes** is the Manufacturing USA Institute dedicated to additive manufacturing, with the U.S. Department of Defense leading federal involvement.

Industry Partner Spotlight:

ORNL partnered with Gate Precast and others to design and print molds out of carbon fiber-reinforced ABS that were used to cast **nearly 1,000 parts** for the façade of a 42-story building in New York City. The 3D-printed molds were

**four times as strong** and **produced in half the time** it takes manual laborers to build traditional wood and fiberglass molds. The new molds can be used as many as 200 times, while conventional molds can typically only withstand 15 to 20 concrete pours.



High-Impact AM & The Current Research Making It Happen

Materials Science:

The MDF has worked with more than 180 companies to create metal and polymer feedstocks to additively manufacture complex objects ranging from human prosthetics to vehicles to molds for appliances, airplane wings, wind turbine blades, and building facades.

Working with Polynt, MDF scientists developed advanced, heat-tolerant polymer materials that can be used to 3D-print large, strong structures suited to aerospace and vehicle applications. As an example, ORNL worked with GE to develop additively manufactured fuel nozzles for aircraft engines.



These components can now be manufactured as **a single piece**, instead of a complex assembly of 20 pieces, resulting in fuel nozzles that **weigh 25 percent less, cost 30 percent less, and are 5 times as durable.** The nozzles went from a concept 5 years ago to a reality today.

High-Performance Computing:

There are several computational tools being used to advance manufacturing processes at ORNL:

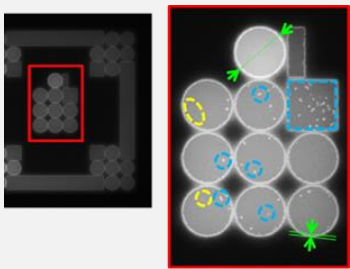
- simulation and analytics of the atomic behavior, interaction and properties of new composites and alloys in materials development;
- machine learning algorithms that can support the control of microstructure in a part and to parse real-time data from printing operations and detect and correct potential defects in-situ that may shorten a part’s lifespan;
- cloud computing to guide entire manufacturing processes for efficient, low-cost operation.



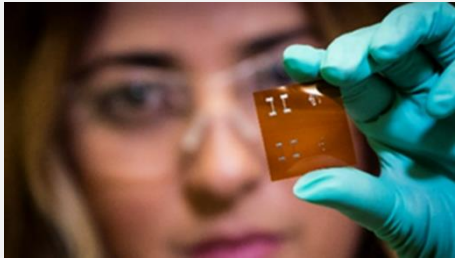
The **Summit** supercomputer at ORNL lets clients take advantage of high-speed **exascale computing (1 quintillion calculations per second)**. MDF researchers use the Summit, sensor data, and simulations to devise **3D-printed parts that are born-qualified (ready to use directly off the printer)**

Sensors/Sensing:

MDF researchers use imaging and other systems to monitor the additive manufacturing process and feed data back to a control system that can then detect and correct any defects while the part is being printed.



Additionally, the MDF has developed highly sensitive, low-cost 3D printed sensors for the DOE which monitor the “health” of the electric grid.



By using direct digital printed radio frequency surface acoustic wave (SAW) technology, these sensors detect dissolved gases caused by electrical, thermal and mechanical stresses that could indicate degradation of transformer components on the nation’s electrical grid. Transformers are very expensive to replace, and the sensors support a low-cost way to monitor their health.

